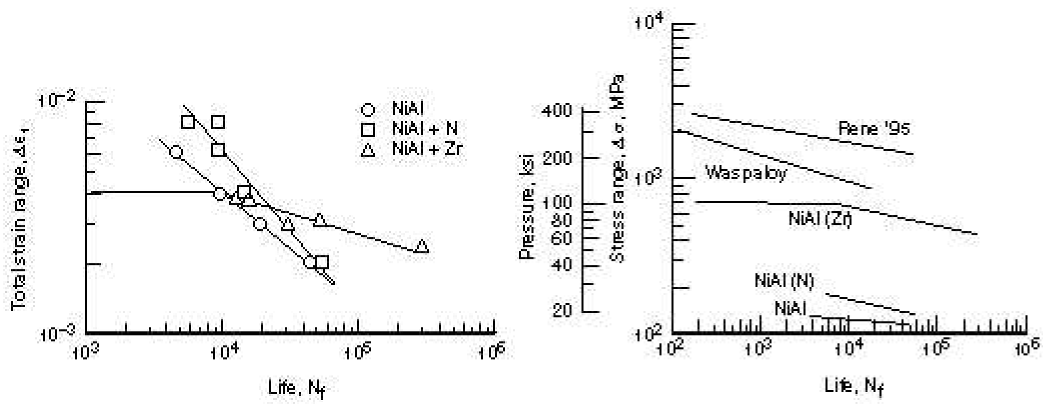
Microalloying Improves the Low-Cycle Fatigue Behavior of Powder-Extruded NiAl

There is considerable interest in developing new structural materials in which high use temperatures and strength, coupled with low density, are the minimum requirements. The goal for these new materials is to provide operation well beyond the working range of conventional superalloys. Of the many intermetallics under consideration, NiAl is one of the few systems that has emerged as a promising candidate for further development. This is because of a number of property advantages--including low density, high melting temperature, high thermal conductivity, and excellent environmental resistance. However, binary NiAl lacks strength and creep resistance at elevated temperatures. Also, its poor high-temperature strength results in worse-than-predicted low-cycle fatigue (LCF) lives at low strain ranges at 727 °C (1341 °F) because of accelerated creep damage mechanisms that result in significant intergranular cracking (refs. 1 and 2). One approach for improving these properties involves microalloying NiAl with either Zr or N. As an integral part of this alloy-development program at the NASA Lewis Research Center, the low-cycle fatigue behavior of Zr- and N-doped nickel aluminides produced by extrusion of prealloyed powders was investigated and compared with similarly processed binary NiAl.

The fatigue-life behavior of the various NiAl alloys is plotted in the first figure. Two stages occurred in the total strain-life plot of NiAl(Zr) because the fracture behavior changed from slow and stable intergranular crack growth at strain ranges less than or equal to 0.38 percent to brittle-cleavage-dominated overload fracture above this value. At strain ranges above 0.38 percent, the peak tensile stress reached the monotonic cleavage fracture stress of the Zr-doped alloy at 1000 K (328 MPa) in less than 100 cycles, enabling fast crack growth by cleavage. At total strain ranges less than or equal to 0.38 percent, the peak tensile cyclic stresses remained at a much lower level than the tensile cleavage fracture stress. In general, fatigue lives are governed by the ductility of the material at high strains and by its strength at low strains. The longer lives of NiAl(Zr) at low strain ranges result from its basic capacity to resist the applied strains on the basis of high strength. Both the NiAl and NiAl(N) alloys have shorter lives at low strain ranges because of the synergistic interaction between fatigue and creep. For the fatigue resistance of the binary and N-doped alloy to be improved, the grain boundaries need to be strengthened by a suitable means to reduce grain-boundary sliding and associated intergranular wedge cracking. Because Zr segregates to the grain boundaries in NiAl (ref. 3) and apparently strengthens the boundary regions, preventing grain-boundary sliding, NiAl(Zr) does not suffer from grain-boundary sliding and intergranular wedge cracking as do the other two alloys.



Left: Fatigue life of three NiAl alloys tested at 727 °C. Right: NiAl alloys compared with typical superalloys tested at a nominal temperature of 727 °C.

Previously it was shown that binary NiAl materials have fatigue lives superior to conventional superalloys when compared on a plastic strain-range basis (ref. 1). This holds true for the additional NiAl alloys studied here. Conversely, the NiAl alloys compared poorly to superalloys when compared on a stress-range basis. However, the current results show that with even an extremely small Zr addition (approximately 0.1 at.%) fatigue life improved significantly on a stress-range basis, approaching that of the superalloys (see second figure). Furthermore, whereas Ni-based superalloys are highly alloyed materials, the NiAl alloy has a significant potential to improve both strength and fatigue life by the incorporation of higher levels of alloying additions.

References

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